NASA TECHNICAL NOTE

NASA TN D-3412

c. 1

NASA TN D-3412

FLIGHT INVESTIGATION OF DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A 0.18-SCALE MODEL OF A FAN-IN-WING VTOL AIRPLANE

by Robert H. Kirby and Joseph R. Chambers

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1966

NASA TN D-3412

FLIGHT INVESTIGATION OF DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A 0.18-SCALE MODEL OF A FAN-IN-WING VTOL AIRPLANE

By Robert H. Kirby and Joseph R. Chambers

Langley Research Center
Langley Station, Hampton, Va.

Technical Film Supplement L-902 available on request.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $2.00

FLIGHT INVESTIGATION OF DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A 0.18-SCALE MODEL OF A FAN-IN-WING VTOL AIRPLANE

By Robert H. Kirby and Joseph R. Chambers
Langley Research Center

SUMMARY

A flight investigation has been made to study the stability and control characteristics of a 0.18-scale model of a fan-in-wing vertical take-off and landing (VTOL) aircraft. The investigation included hovering flight, both in and out of ground effect, and fan-powered low-speed forward flight. The hovering-flight tests out of ground effect showed that the controls-fixed motions of the model without artificial stabilization consisted of unstable oscillations in pitch and roll. The model was easy to control in pitch, but was difficult to control in roll during hovering and low-speed forward flight as a result of its sensitivity to disturbances. The model required an increasing nose-down pitch trim during the early part of the fan-powered forward flight, and a pitching moment, corresponding to a nose-fan lift reversal of 12 percent, was required to trim the model at speeds above 25 knots (59 knots full scale). The model was easy to control in yaw at all airspeeds tested.

INTRODUCTION

The gas-coupled high-bypass-ratio lift-fan concept has been proposed as a means to permit optimization of both cruise and lift propulsion in V/STOL aircraft. A number of large-scale force-test investigations of this concept have been made in the Ames 40- by 80-foot (12.2- by 24.4-m) wind tunnel and are reported in references 1 to 4. After these investigations, a fan-in-wing flight-research aircraft was developed to determine the performance and suitability of the lift-fan-propulsion concept for V/STOL aircraft. This aircraft has two lift fans mounted in the wings and a smaller fan in the nose of the aircraft for pitch control. All three fans are powered by two J85 turbojet engines. The turbojet engines supply power both for vertical take-off and landing and for cruising flight. For vertical flight, diverter valves installed behind the engines direct the turbojet exhaust to lift-fan tip turbines which drive the lift fans. The multiplying factor between engine thrust and fan lift is almost three. After vertical take-off, transition to forward flight is accomplished by deflecting vanes (louvers) mounted beneath each wing fan. After sufficient speed is attained for wing-supported flight, the diverter valves redirect the engine exhaust through conventional engine tailpipes and nozzles to provide thrust for cruising flight, and the lift fans are stopped and covered over to form smooth wing and fuselage contours.

The present investigation was made to determine the dynamic stability and control characteristics in the hovering and transition flight conditions of an approximately 0.18-scale model of the fan-in-wing VTOL research aircraft designated the XV-5A. The forward-flight speeds investigated covered the fan-powered range between hovering and the speed at which conversion would be made to jet-powered flight. The conversion maneuver was not investigated. The flying-model investigation was performed in the Langley full-scale tunnel, and the flight-test results were obtained mainly from pilot observations and from studies of motion-picture records of the flights.

A motion-picture film supplement (L-902) has been prepared and is available on loan. A request card and a description of the film will be found at the back of this paper.

SYMBOLS

To facilitate international usage of data presented, the equivalent dimension in the International System of Units (SI) is given parenthetically after each dimension in the U.S. Customary Units. The equivalent dimensions were determined by using the conversion factors presented in the appendix. Scales in SI units, where needed, are placed to the right of the figures. Scaling factors for dimensional quantities (ref. 5) are given in table I.

The forces and moments are referenced to the model center of gravity which was 2.5 inches (6.35 cm) ahead of the wing-fan center line and in the plane of the wing upper surface.

D wing-fan diameter, feet (meters)

F_L force in lift direction, pounds force (newtons)

F_X force along longitudinal body axis, positive forward, pounds force (newtons)

h height of model wheels above ground ($\theta = 0^{\circ}$), feet (meters)

I_X moment of inertia about longitudinal body axis, slug-feet^2 (kilogram-meters^2)

I_Y moment of inertia about lateral body axis, slug-feet^2 (kilogram-meters^2)

I_Z moment of inertia about vertical body axis, slug-feet^2 (kilogram-meters^2)

V forward velocity, knots

α angle of attack, degrees

δ_l louver deflection measured from vertical, degrees

θ fuselage pitch angle, degrees

APPARATUS AND TESTS

Model

General characteristics.- The 0.18-scale flying model is shown in the photographs of figure 1, and a three-view sketch showing some of the more important model dimentions is shown in figure 2. Additional dimensions and other geometric characteristics of the model are given in table II. The primary model airframe consisted of molded glass fiber outer contour supported by an internal frame of aluminum. The model had a midwing which was equipped with outboard ailerons and inboard single-slotted flaps as indicated by the sketch of figure 2. During this investigation, all flights at forward speed were made with the ailerons drooped 15° and the flaps deflected 45° to agree with similar deflections expected to be used on the full-scale aircraft during fan-powered flight. The model had an all-movable horizontal tail in a T-tail arrangement.

The model had a geometrically scaled lift fan in each wing panel and a smaller fan located in its nose for pitch control as shown in the photograph of figure 1(a). Also shown in the photograph are the closure doors used to seal the wing fan inlets on the full-scale airplane during conventional flight. The closure doors remained in the open position for all tests in this investigation. A single wing-fan assembly is shown in figure 3(a). Figure 3(b) shows the major components of a wing fan: the inlet frame, fan stator vanes and turbine stators, the exit-louver assembly, and the fan assembly and turbine scroll. The blades and stators were of molded glass fiber construction as is indicated by a typical stator vane shown at the bottom of the photograph.

The fans were tip driven by compressed air through an ejector system as shown in figure 4. This ejector system was used to more closely simulate, with the high-pressure air supply, the low pressure, high-mass-flow characteristics of the full-scale fan drive system. The compressed-air ejector system also helped simulate the inflow to the turbojets of the full-scale vehicle.

Vectoring of the wing fan exhaust by the remotely operated exit louvers provided the longitudinal thrust necessary for forward flight. The performance of these louvers, which had cambered airfoil sections, is shown in figure 5 where it is compared with the estimated louver performance on the full-scale aircraft.

Controls.- During fan-powered flight, the full-scale aircraft obtains all its control from either spoiling (staggering of louvers or deflection of adjacent louvers toward each other) or vectoring the fan thrust. The wing-fan exit louvers provide height control through thrust spoiling, roll control through differential thrust spoiling, and yaw control through differential thrust vectoring. The lower fuselage section below the pitch fan opens in the fan-powered mode to form a fan-flow modulator or reverser. (See fig. 1(b).) Pitch trim and maneuver control is obtained from this pitch-fan modulator on the full-scale aircraft.

For this investigation, however, jet-reaction controls were used about the three body axes of the model for attitude control, and height control was obtained by changing fan speed. Control jets at the wing tips gave roll control and jets at the tail gave yaw and pitch control. The jet-reaction controls were used on the model so that the basic stability and controllability of the configuration could be studied without the possibility of a confusing effect of the unusual control system of the full-scale aircraft.

The maximum jet-reaction control moments available and the accelerations produced by these moments were:

Axis	Control moment		Acceleration, rad/sec^2
	ft-lb	m-N	
Pitch	±16.0	±21.7	±2.7
Roll	± 4.5	± 6.1	±2.7
Yaw	±13.0	±17.6	±2.0

The aileron and rudder surfaces were interconnected to the roll and yaw control jets so that in forward flight, roll and yaw control were provided by a combination of jet-reaction control and conventional aerodynamic control.

The jet-reaction controls were actuated by flicker-type (full-on or full-off) pneumatic mechanisms which were remotely operated by the pilots by means of solenoid-operated valves. Each actuator had a motor-driven trimmer which was electrically operated by the pilots so that the controls could be rapidly trimmed independently of the flicker control deflections.

Although pitch control for maneuvering was obtained from a tail jet in this investigation, the pitch-fan modulator doors were used for pitch trim because the fan exhaust diverted sideways by these doors might have important aerodynamic interference effects on the wing. Figure 6 shows the characteristics of the modulator on the model as compared with the estimated full-scale performance. Figure 6 shows that good simulation was obtained down to the position where all the pitch fan lift was spoiled but that the model did not achieve as much reversed thrust as was estimated for the full-scale modulator. No attempt was made in this investigation to improve the reversing on the model, however, since it was planned on the aircraft to reserve the reverse lift of the pitch fan for maneuver control, which was being obtained on the model from reaction jets.

Tests

The investigation consisted of free-flight tests to determine the dynamic stability and control characteristics of the model during vertical take-off and landing, in hovering flight both in and out of ground effect, and in forward flight up to a model speed of about 41 knots (97 knots full scale). This speed corresponds approximately to the point at which conversion to wing-borne jet-powered flight would be made, but the conversion maneuver was not investigated in these tests. The results were mainly qualitative and consisted of pilot observations and opinions of the behavior of the model. Motion-picture records were made of all flights for further study.

The hovering tests out of ground effect were performed by hovering the model at a height of 15 to 20 feet (4.6 to 6.1 m) above the ground. In these tests the uncontrolled pitching and rolling motions and the ease with which these motions could be stopped after they had been allowed to develop were examined. The roll characteristics of the model in hovering flight were further investigated to determine the effect of an increase in roll inertia and also the effect of an addition of wing fences.

Hovering tests in ground effect consisted of flying the model within about a foot (0.3 m) of the ground to determine the effect of ground proximity on stability and on the power required for steady flight. Take-offs and landings were conducted with the model trimmed for steady hovering flight out of ground effect.

Forward flights were made at various fixed airspeeds to determine the stability and control of the model at several speeds in the fan-powered flight range. Flights were also made with the nose fan inoperative to evaluate the contribution of the nose fan to the stability of the model.

Test Setup and Flight Test Technique

The test setup for the forward-flight tests made in the Langley full-scale tunnel is shown in figure 7. The model was flown without restraint in the 30- by 60-foot (9.1- by 18.3-m) open-throat test section of the tunnel. The model was remotely controlled about all three body axes by human pilots. The pilots who control the model about its roll and yaw axes were located in an enclosure at the rear of the test section where they could best view the lateral motions of the model. The pitch pilot, model power operator, and safety-cable operator were stationed at the side of the test section. Pneumatic and electric power and control signals were supplied to the model through the flexible trailing cable which was made up of wires and light plastic tubes. This trailing cable also incorporated a 1/8-inch (0.318-cm) steel cable that passed through a pulley above the test section. This cable was used as a safety cable to catch the model if an uncontrollable motion or mechanical failure occurred. The reasons for using this model flight technique in which the piloting duties are divided, in preference to the conventional single-pilot technique, is explained in detail in reference 6. In forward flight two pilots were sometimes used with one pilot controlling both roll and yaw and the other controlling pitch.

As a typical flight began, the model hung from the safety cable with zero tunnel airspeed. The tunnel drive motors were then started and the particular test airspeed was established. The compressed air power to the model fans was then increased and the exit louvers were pivoted rearward until the model was in equilibrium flight at the desired attitude and airspeed.

Hovering-flight tests were made by using the same technique and setup except that the tunnel test section was not used. The tests were performed in a large enclosed area which provided protection from random disturbances due to wind and was large enough to minimize slipstream recirculation effects.

RESULTS AND DISCUSSION

A motion-picture film supplement (L-902) has been prepared and is available on loan. A request card and a description of the film will be found at the back of this paper.

Hovering Flight

Out of ground effect.- In hovering flight out of ground effect the model without artificial stabilization had unstable controls-fixed oscillations in both pitch and roll. Figure 8 shows time histories of typical pitch and roll oscillations which were obtained from motion-picture records of flight tests in which the pilot held the control in a neutral position and allowed the oscillation to develop. The data of figure 8 show that the period of the pitch and roll oscillations and the degree of instability were fairly similar. The pilots found, however, that the model was easy to control in pitch despite the unstable pitching oscillation, but was very difficult to control in roll – even with control power about each of the two axes set at the most desirable value for that axis. The reason for this difference seemed to be that the model was much more sensitive to disturbances in roll than in pitch. This sensitivity probably resulted from the fact that the model had a very high dihedral effect (rolling moment due to sidewise velocity) and relatively low moment of inertia in roll. The roll disturbances were random fluctuations in the recirculating fan slipstream in the large enclosure where the tests were made or inadvertent sideslipping of the model. No measurements except the qualitative observations of persons standing near the model have been made with this, or any other model, to determine the gustiness of the air in the test area. From such observations, however, it seems that the velocity changes involved in the disturbances are probably small compared with those that would be encountered outdoors on a gusty day, but they might have been more frequent than outdoor gust disturbances.

As part of the investigation of the rolling motions of this model, the moment of inertia in roll was increased 30 percent in an attempt to reduce the response of the model to disturbances. This change gave some improvement in the ease with which the pilot could control the model in roll. There might be some question whether the improvement in controllability of the model with increased moment of inertia resulted from a decreased sensitivity to disturbances or from a slight increase in the period of the rolling oscillation. However, the period of the oscillation for the basic condition was at least 4 seconds (model scale), which is not critically short, so that the increase in period would not seem to be the important factor.

As another part of the investigation of the roll characteristics in hovering, chordwise fences were installed on the upper surface of the wing just outboard of each wing fan. (See fig. 9.) These fences, which did not appreciably affect the static thrust, were 1.5 inches (3.81 cm) high. The installation of the fences made the model much easier to control in roll. The time histories of figure 10 indicate similar control-fixed rolling motions of the model with or without the fences installed. Measurements made from these time histories, however, indicate that the use of the fences reduced the instability by one-half (from about 0.55 second to double amplitude to about 1.10 seconds to double amplitude). It appeared to the pilot, however, that the improvement from the use of the fences was not so much a result of a reduced instability as it was a result of a reduction in the sensitivity of the model to a disturbance, particularly a reduction in the rolling moment due to sidewise velocity. A contributing factor might also have been that the pilot required a high control sensitivity to contend with the erratic, large-amplitude motions of the basic model and this high sensitivity resulted in some overcontrolling pilot-induced disturbances. The steadier flight conditions resulting from the installation of the fences allowed a reduction in the control sensitivity to a level where pilot overcontrolling was not a factor in the model flight behavior.

All the foregoing tests had been made without the use of artificial stabilization. One further investigation was made with the model equipped with artificial-stabilization equipment to provide additional damping in roll. This equipment consisted of a servomechanism connected to the roll-control jet that was actuated by a rate-sensitive gyroscope to give rolling moment to oppose rolling velocity. It was found that the addition of sufficient artificial damping in roll completely stabilized the rolling oscillation and reduced the response to disturbances to the point that the rolling motions of the model became very easy to control.

No corresponding study of the pitching motions was made since the model was sufficiently easy to control in its basic condition without stability augmentation.

The model had neutral stability in yaw during hovering flight, and yaw control was required to keep the model properly oriented with respect to the various pilots. The yaw pilot had no difficulty in maintaining a constant heading during these flight tests. The total control moments available on the model, given previously in the section entitled "Models," were found to be completely adequate to deal with the hovering motions of the model, although a detailed investigation of the minimum requirements was not made.

In ground effect.- When trimmed for hovering flight out of ground effect, the model would pitch nose-up slightly before leaving the ground during take-offs and would translate rearward slightly when nearing the ground during landings, apparently as a result of a slight nose-up pitching motion. This nose-up pitching motion was probably due to a positive pressure acting on the underside of the fuselage forward of the center of gravity because of an upward flow of the fan slipstreams between the nose and wing fans. The pitch pilot did not consider the pitch-up tendency to be a problem because of the low angular velocity of the pitch-up and the small amount of control moment required to trim the model.

It was not possible to fly the model close to the ground for a long enough period of time, or smoothly enough, to determine the ground effect on lift and stability in detail, mainly because of unsteadiness in roll which was apparently the same sensitivity in roll previously discussed for hovering flight out of ground effect. There were no ground effects, however, which were sufficiently outstanding to be definitely discernible to the pilot.

A few force tests were made to investigate the characteristics of the model in ground effect. The results of these tests, made at constant fan speed, were masked to a certain extent by an unsteadiness or scatter in some of the data, particularly in the roll data. In general, however, the data indicated very little effect of the ground on either lift or stability. The data were fairly steady about the pitch axis and figure 11 shows some of these pitching-moment data. The change in pitching-moment trim as the model nears the ground is shown in figure 11(a) and the variation of pitching moment with attitude is shown in figure 11(b), which indicates a slight, statically stabilizing effect of ground proximity.

Forward Flight

The forward-flight tests were made in the level-flight condition for the fan-powered flight range from hovering to about 41 knots (97 knots full scale). This speed is approximately that at which the full-scale aircraft would convert to wing-borne jet-powered flight, but this maneuver was not attempted in the present investigation. It should be noted again that the ailerons were drooped 15^{o} and the flaps were deflected 45^{o} during all the forward-flight tests reported herein.

Longitudinal stability.- The basic stability of the model throughout the fan-powered flight range was determined during constant-airspeed flight tests with the model trimmed for flight at $\alpha = 0^{o}$. Examples of the types of motion experienced are shown in figure 12 which presents time histories of the control-fixed pitching motions for various airspeeds. This figure shows that the pitching oscillation present in hovering became less unstable as the airspeed was increased. The model appeared to be stable at the highest speeds reached in the tests. In any event, the period of the oscillations was relatively long, even in hovering, and the pitch pilot considered the model to be easy to fly throughout the fan-powered flight range.

Several flights were made with the nose fan inoperative but with the fan inlet and exit open. These tests indicated that the pitch-fan contribution to the longitudinal characteristics was slightly destabilizing (less stable variation of pitching moment with angle of attack).

Longitudinal trim.- Figure 13 shows the exit-louver deflection and fan speed required for trimmed forward flight for several fuselage angles of attack. The scatter in the exit-louver-deflection data resulted mainly from the low degree of accuracy with which the deflection angle on the very small cambered-airfoil louvers and the fuselage angle of attack during flight could be measured. In general, the data indicate that a 5^{o} increase in attitude required a corresponding 5^{o} increase in louver deflection and was accompanied by a decrease in required fan speed. The decrease in fan speed evidently resulted from the fact that, at the higher angle of attack, the wing provided more of the necessary lift. With a lower fan airflow, the fan momentum drag would be lower and would tend to offset an increase in airframe drag.

Figure 14 shows the pitch trim required for forward flight with the fuselage level. The figure also indicates the horizontal-tail incidence used to obtain the pitch-trim data presented. These tail settings roughly correspond to the incidence variation that is expected to be used on the full-scale aircraft. Actually, the tail incidence was varied during these model flight tests and the variation shown in figure 14 gave about the maximum pitching moment achievable without encountering stall on the tail.

The data of figure 14 indicate that the model required an increasing nose-down pitch trim during the early part of the fan-powered flight and that a pitching moment corresponding to a nose-fan lift reversal of 12 percent is required to trim the model at forward speeds above 25 knots (59 knots full scale). As shown on figure 6, the model did not have the required nose-fan reverse-lift capability. The additional pitching moment required above 19 knots was therefore obtained from the jet-reaction control at the tail which was normally used only for maneuvering control on the model. These model flight tests indicated that the pitching moment originally available on the full-scale aircraft probably would not be sufficient for both trim and maneuvering control. Actually, after these model flight tests were made, both the nose-fan lift and reversal capability on the full-scale aircraft were increased to obtain sufficient control power. However, this model investigation was completed before these modifications were made and these control modifications were not tested.

Lateral characteristics.- The difficulty experienced with roll control in hovering flight persisted in forward flight. Most of the forward-flight tests were made, therefore, with artificial damping in roll while the other model characteristics were being investigated. The model was easy to fly with the roll damper installed and exhibited no objectionable lateral characteristics. By varying the roll damping, it was found that the basic lateral characteristics improved as forward speed increased, and at speeds above 30 knots (70 knots full scale), the model could be controlled reasonably satisfactorily without artificial damping.

The model was easy to control in yaw at all airspeeds tested. The pilot felt that the model was directionally stable at speeds above 17 knots (40 knots full scale). A few flights were made with the nose fan inoperative and the yaw pilot found that the model was even slightly easier to fly in this condition. This improvement probably resulted from the elimination of the statically destabilizing contribution of the nose-fan momentum drag.

SUMMARY OF RESULTS

The results of the flight tests of a 0.18-scale model of a fan-in-wing VTOL airplane are summarized as follows:

1. Hovering-flight tests out of ground effect showed that the basic controls-fixed motions of the model without artificial stabilization consisted of unstable oscillations in pitch and roll. The model was neutrally stable in yaw during hovering flight.

2. The pilots found that the model was easy to control in pitch despite the unstable oscillation, but was difficult to control in roll during hovering flight. It seemed that the reason for this difference was that the model was more sensitive to disturbances in roll than in pitch because of a very high dihedral effect.

3. Increased moment of inertia in roll, the addition of wing fences, and the use of artificial damping in roll all made the model easier to control in roll by decreasing its sensitivity to random disturbances.

4. The control-fixed longitudinal oscillation present in hovering became less unstable as forward speed increased and seemed to be stable at the highest speeds tested.

5. The model required increasing nose-down pitch trim during the early part of the fan-powered forward flight. A pitching moment, corresponding to a nose-fan lift reversal of 12 percent, was required to trim the model at speeds above 25 knots (59 knots full scale).

6. The unstable rolling oscillations experienced in hovering flight persisted in forward flight, but the instability decreased with increasing airspeed.

7. The model was easy to control in yaw at all airspeeds tested and was directionally stable at speeds above about 17 knots (40 knots full scale).

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 1, 1966.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

Factors for converting U.S. Customary Units to the International System of Units (SI) are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI unit
Area	in^2	6.4516	centimeters^2 (cm^2)
	ft^2	0.0929	meters^2 (m^2)
Force	lbf	4.4482	newtons (N)
Length	in.	0.0254	meters (m)
	ft	0.3048	meters (m)
Moment	ft-lbf	1.3558	newton-meters (N-m)
Moment of inertia . . .	slug-ft^2	1.3558	kilogram-meters^2 (kg-m^2)
Pressure	lbf/ft^2	47.8802	newtons/meter^2 (N/m^2)
Velocity	ft/min	0.0051	meters/second (m/s)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI Unit.

Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
centi (c)	10^{-2}
milli (m)	10^{-3}

REFERENCES

1. Aoyagi, Kiyoshi; Hickey, David H.; and deSavigny, Richard A.: Aerodynamic Characteristics of a Large-Scale Model With a High Disk-Loading Lifting Fan Mounted in the Fuselage. NASA TN D-775, 1961.
2. deSavigny, Richard A.; and Hickey, David H.: Aerodynamic Characteristics in Ground Effect of a Large-Scale Model With a High Disk-Loading Lifting Fan Mounted in the Fuselage. NASA TN D-1557, 1963.
3. Hickey, David H.; and Hall, Leo P.: Aerodynamic Characteristics of a Large-Scale Model with Two High Disk-Loading Fans Mounted in the Wing. NASA TN D-1650, 1963.
4. Kirk, Jerry V.; Hickey, David H.; and Hall, Leo P.: Aerodynamic Characteristics of a Full-Scale Fan-in-Wing Model Including Results in Ground Effect With Nose-Fan Pitch Control. NASA TN D-2368, 1964.
5. Shortal, Joseph A.; and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation With Full-Scale Flight Tests. NACA TN 810, 1941.
6. Parlett, Lysle P.; and Kirby, Robert H.: Test Techniques Used by NASA for Investigating Dynamic Stability Characteristics of V/STOL Models. J. Aircraft, vol. 1, no. 5, Sept.-Oct. 1964, pp. 260-266.

TABLE I.- SCALING FACTORS

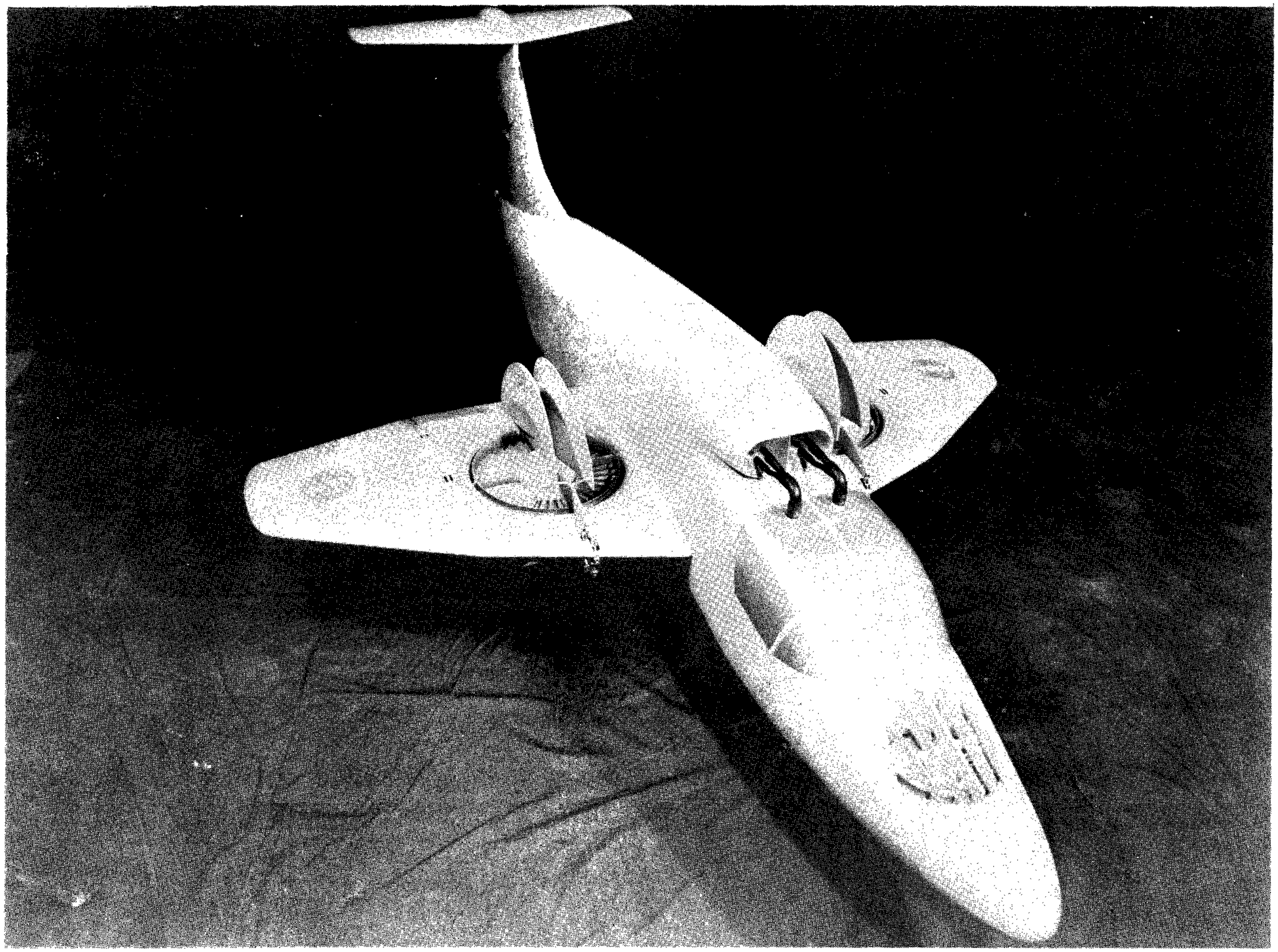
$\left[\text{Model scale} = 0.18 \text{ or } \frac{1}{5.56}\right]$

Model dimensional quantity	Scaling factors (*)
Length	5.56
Weight	$(5.56)^3$
Area	$(5.56)^2$
Inertia	$(5.56)^5$
Linear velocity	$(5.56)^{1/2}$
Angular velocity	$(5.56)^{-1/2}$

*Multiply value of model dimensional quantity by scaling factor to obtain full-scale value. (See ref. 5.)

TABLE II.- MASS AND GEOMETRIC CHARACTERISTICS OF THE MODEL

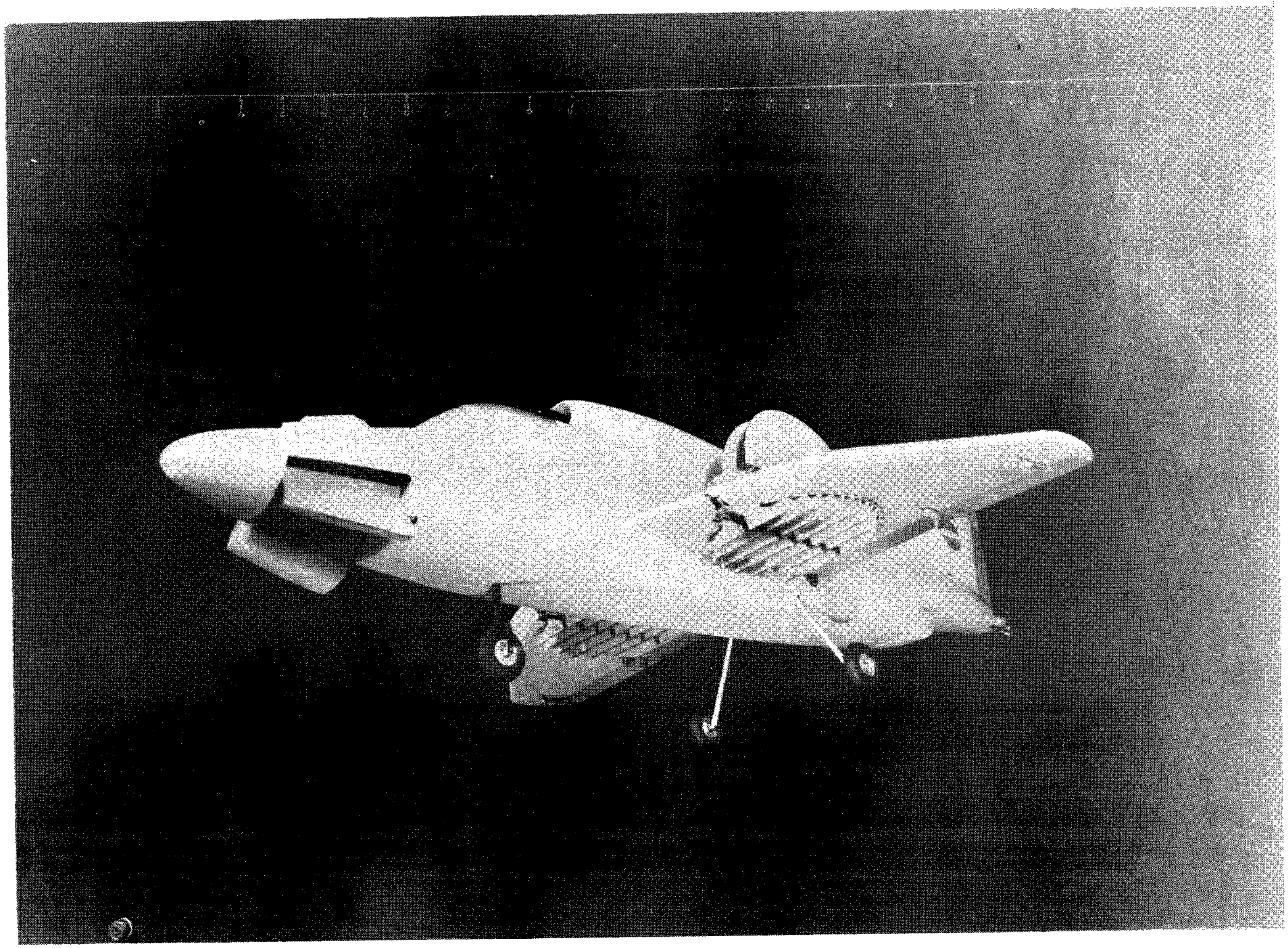
Weight	62 lb	(276 N)
Moment of inertia:		
I_X	1.58 slug-ft^2	(2.14 kg-m^2)
I_Y	5.77 slug-ft^2	(7.82 kg-m^2)
I_Z	6.65 slug-ft^2	(9.02 kg-m^2)
Fans:		
Nose fan diameter	0.54 ft	(16.46 cm)
Wing fan diameter	0.94 ft	(28.65 cm)
Wing:		
Area	8.47 ft^2	(0.79 m^2)
Span	5.40 ft	(1.65 m)
Chord:		
Root	2.17 ft	(66.14 cm)
Outboard end of center section	1.64 ft	(49.99 cm)
Theoretical tip	0.65 ft	(19.81 cm)
Mean aerodynamic chord	1.68 ft	(51.21 cm)
Aspect ratio		3.44
Airfoil section		NACA 65-210 (modified)
Sweepback (quarter chord):		
Center section		15°
Outer section		28°
Dihedral angle:		
Center section		0°
Outer section		-6°
Geometric twist (washout):		
Center section		0°
Outer section		3°
Ailerons (each):		
Chord (percentage wing chord)		25.00
Area	0.38 ft^2	(0.04 m^2)
Flap:		
Type		Single slotted
Chord	0.38 ft	(11.58 cm)
Area	0.89 ft^2	(0.08 m^2)
Vertical tail:		
Area	1.65 ft^2	(0.15 m^2)
Span	1.40 ft	(42.67 cm)
Chord:		
Root	1.51 ft	(46.02 cm)
Tip	0.81 ft	(24.69 cm)
Aspect ratio		1.18
Taper ratio		0.52
Airfoil section		NACA 64_1A012
Sweepback (quarter chord)		30°
Rudder:		
Root chord	0.26 ft	(7.92 cm)
Tip chord	0.18 ft	(5.49 cm)
Area	0.20 ft^2	(0.02 m^2)
Horizontal tail:		
Area	1.64 ft^2	(0.15 m^2)
Span	2.22 ft	(67.67 cm)
Chord:		
Root	0.99 ft	(30.18 cm)
Tip	0.49 ft	(14.94 cm)
Aspect ratio		3.00
Taper ratio		0.50
Airfoil section		NACA 64_1A012
Sweepback (quarter chord)		13.70°



(a) Top view of model.

L-62-9775

Figure 1.- Photographs of model.



L-62-9773

(b) Bottom view of model.

Figure 1.- Concluded.

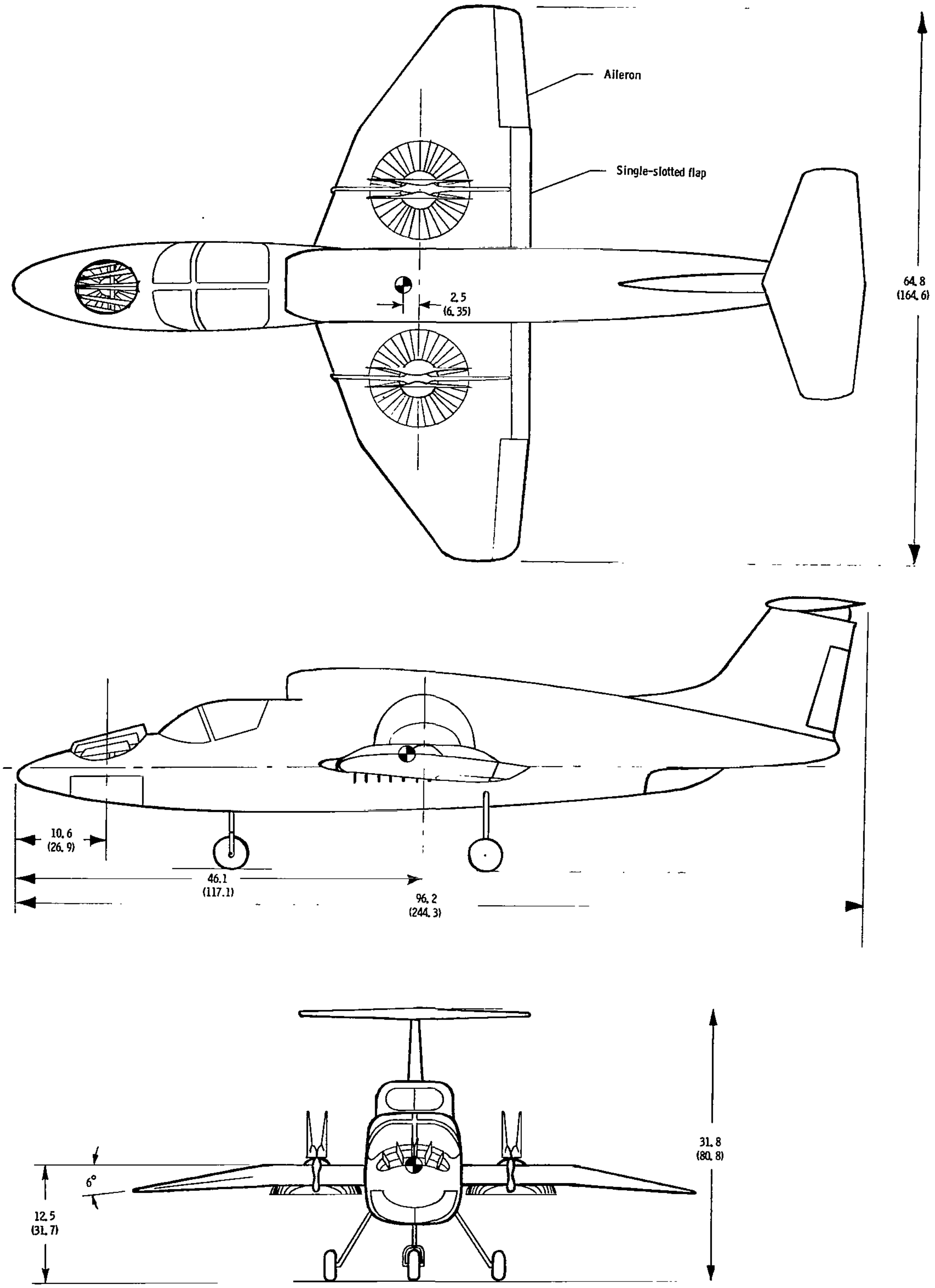
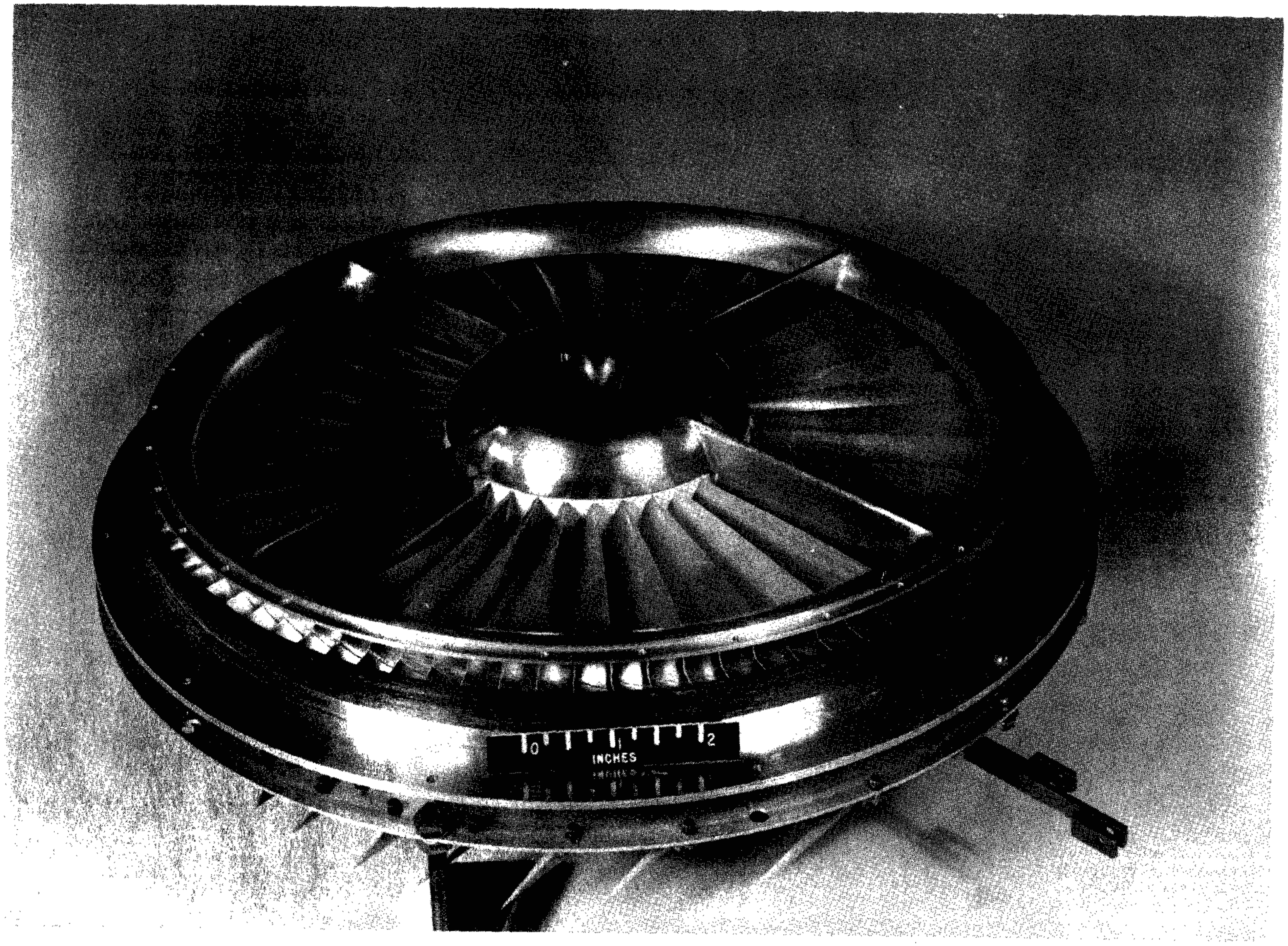


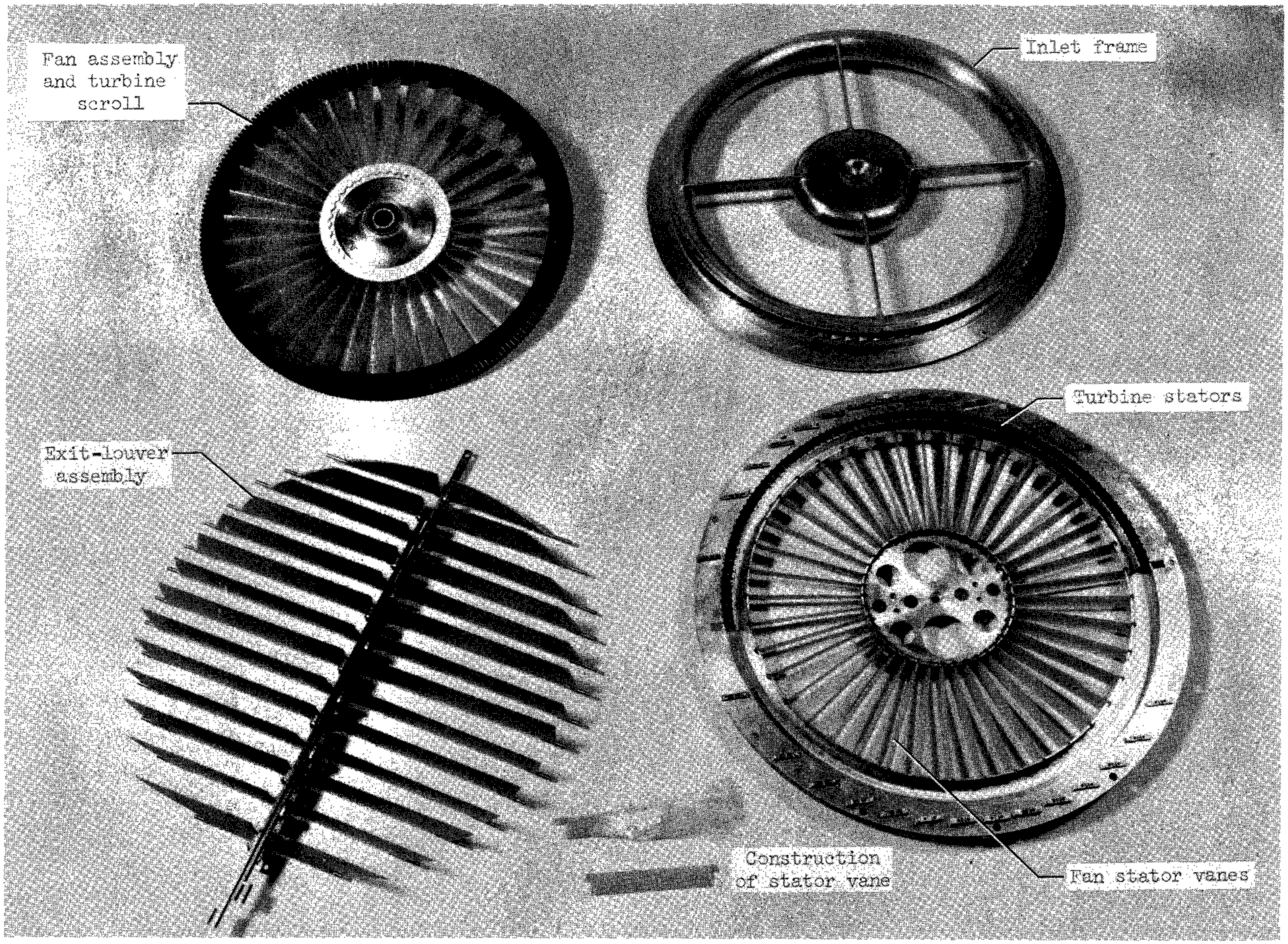
Figure 2.- Three-view sketch of model. Dimensions are given in inches and parenthetically in centimeters.



(a) Assembled without inlet guide vanes.

L-62-4483

Figure 3.- Photographs of a wing fan.



(b) Fan subassemblies.

L-62-4485.1

Figure 3.- Concluded.

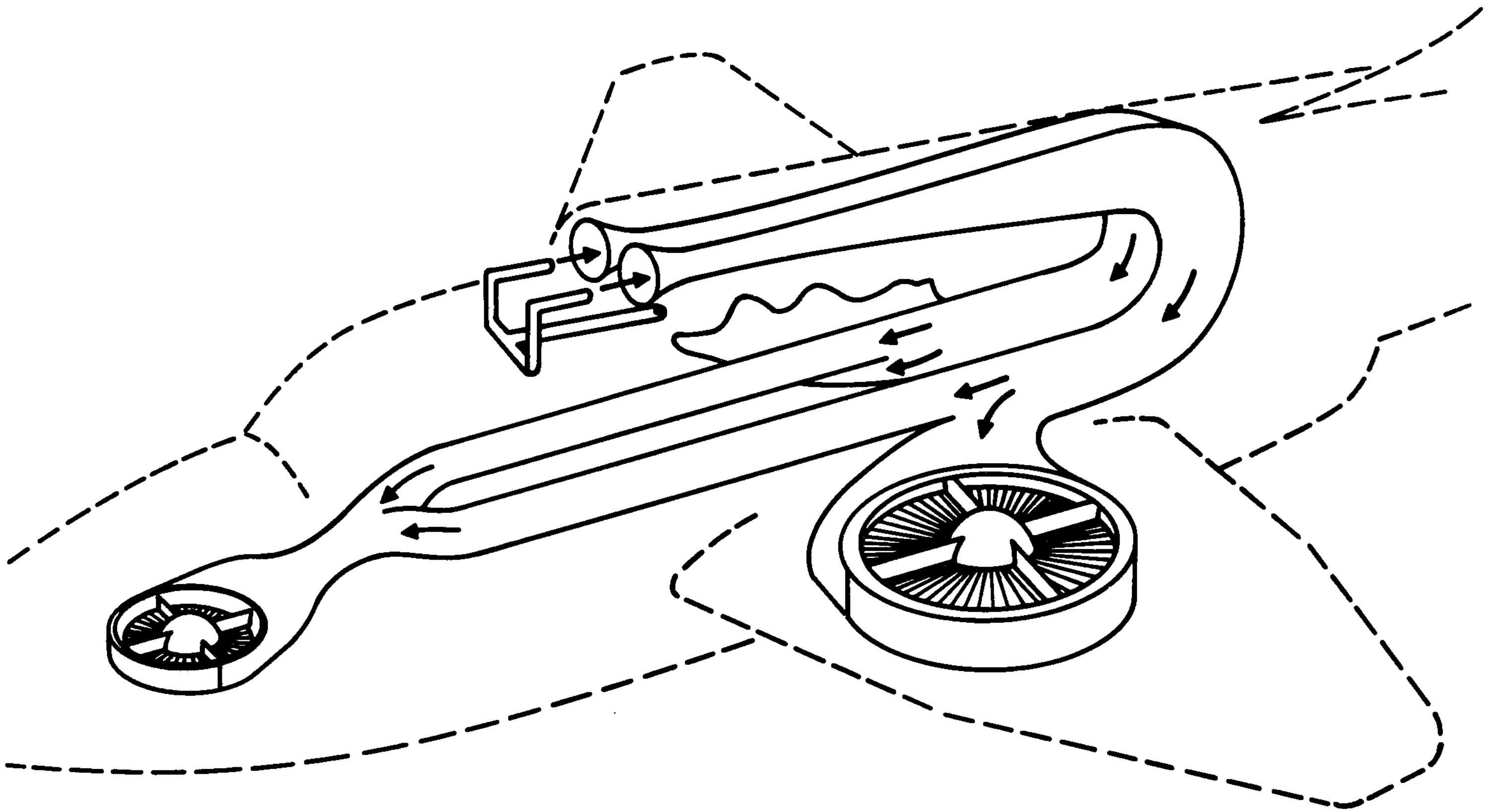


Figure 4.- Compressed-air ejector system used to drive model fans.

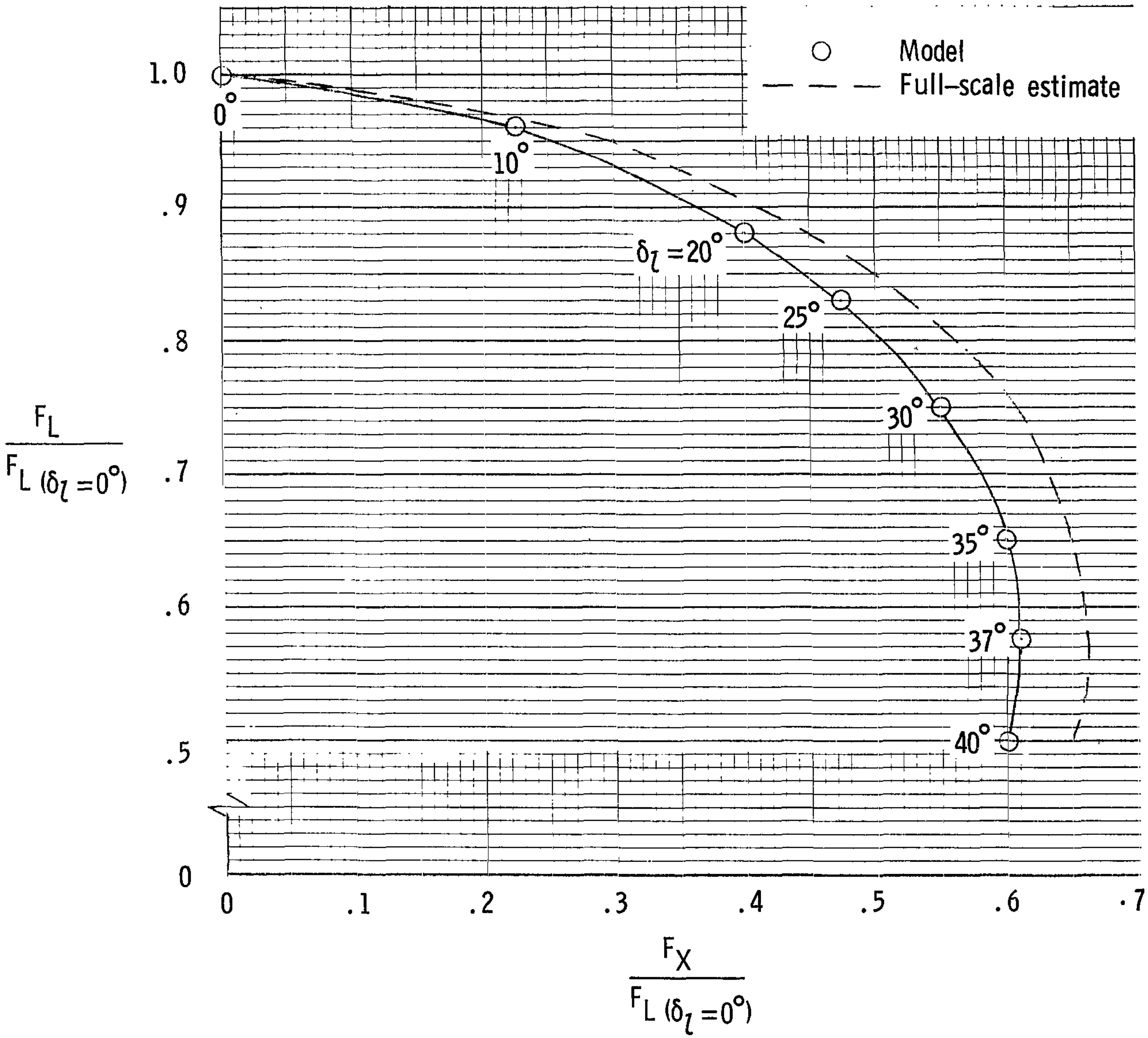


Figure 5.- Comparison of model and full-scale exit-louver performance at constant rpm. V = 0.

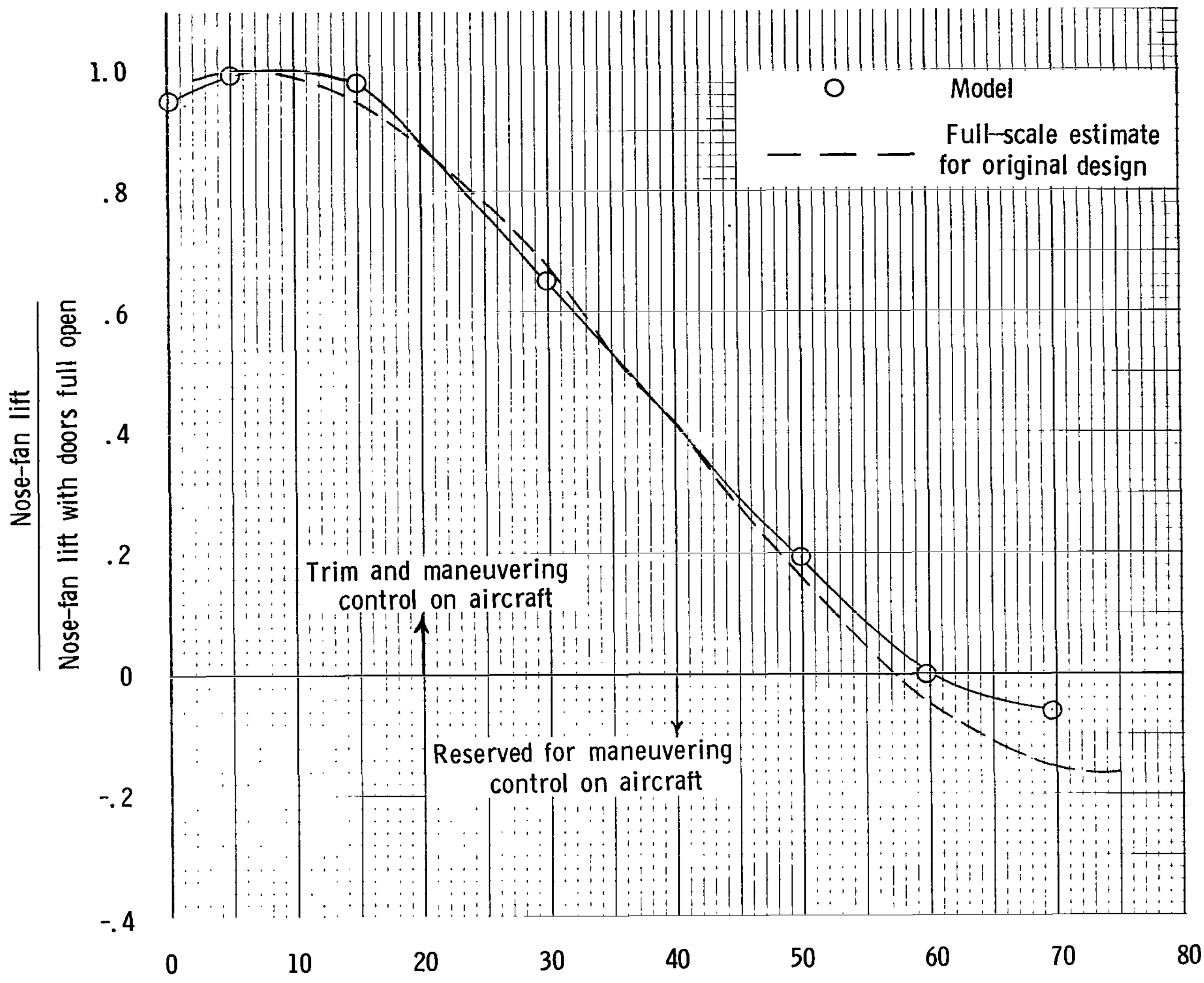


Figure 6.- Comparison of model and full-scale pitch-fan modulator effectiveness.

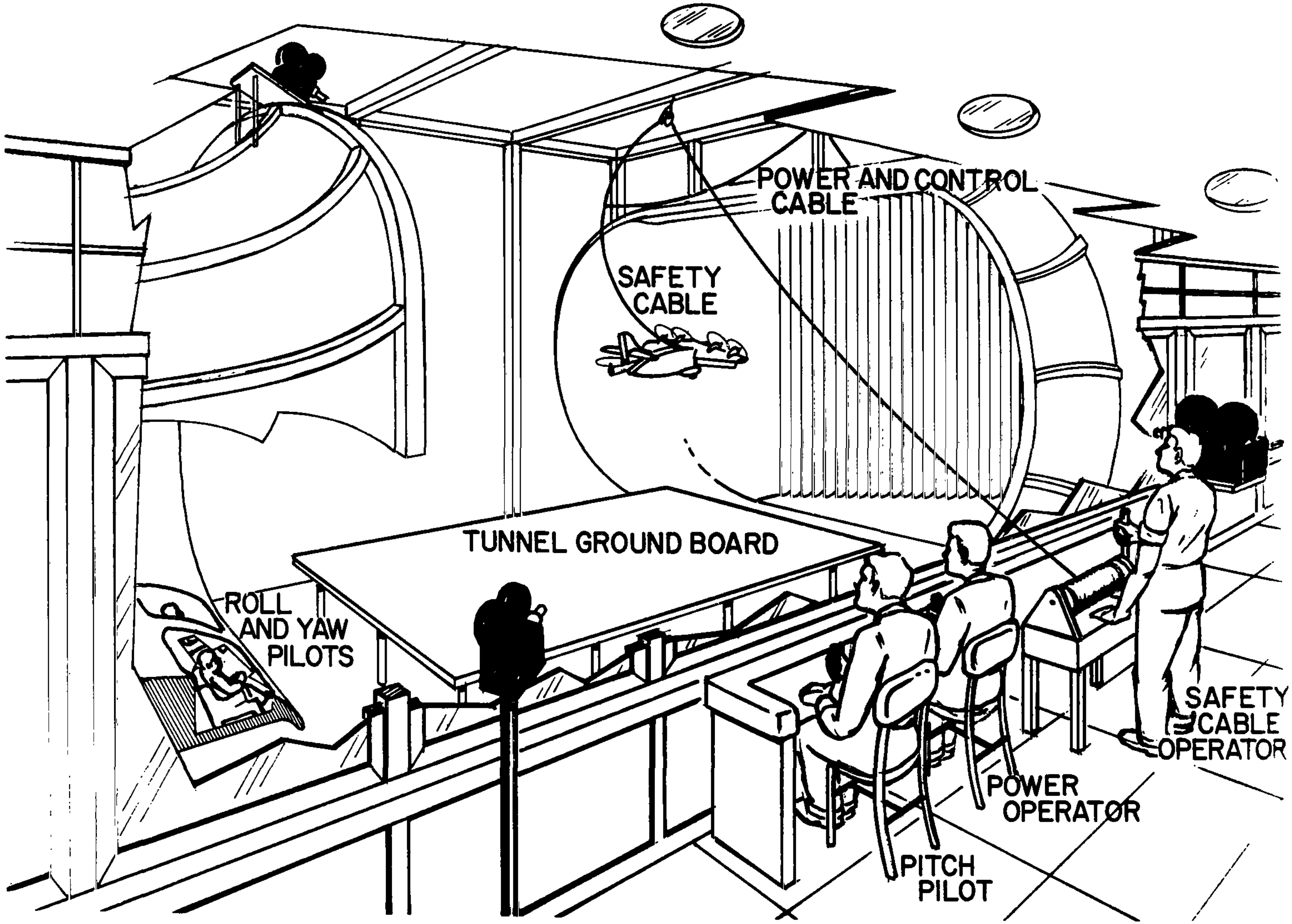
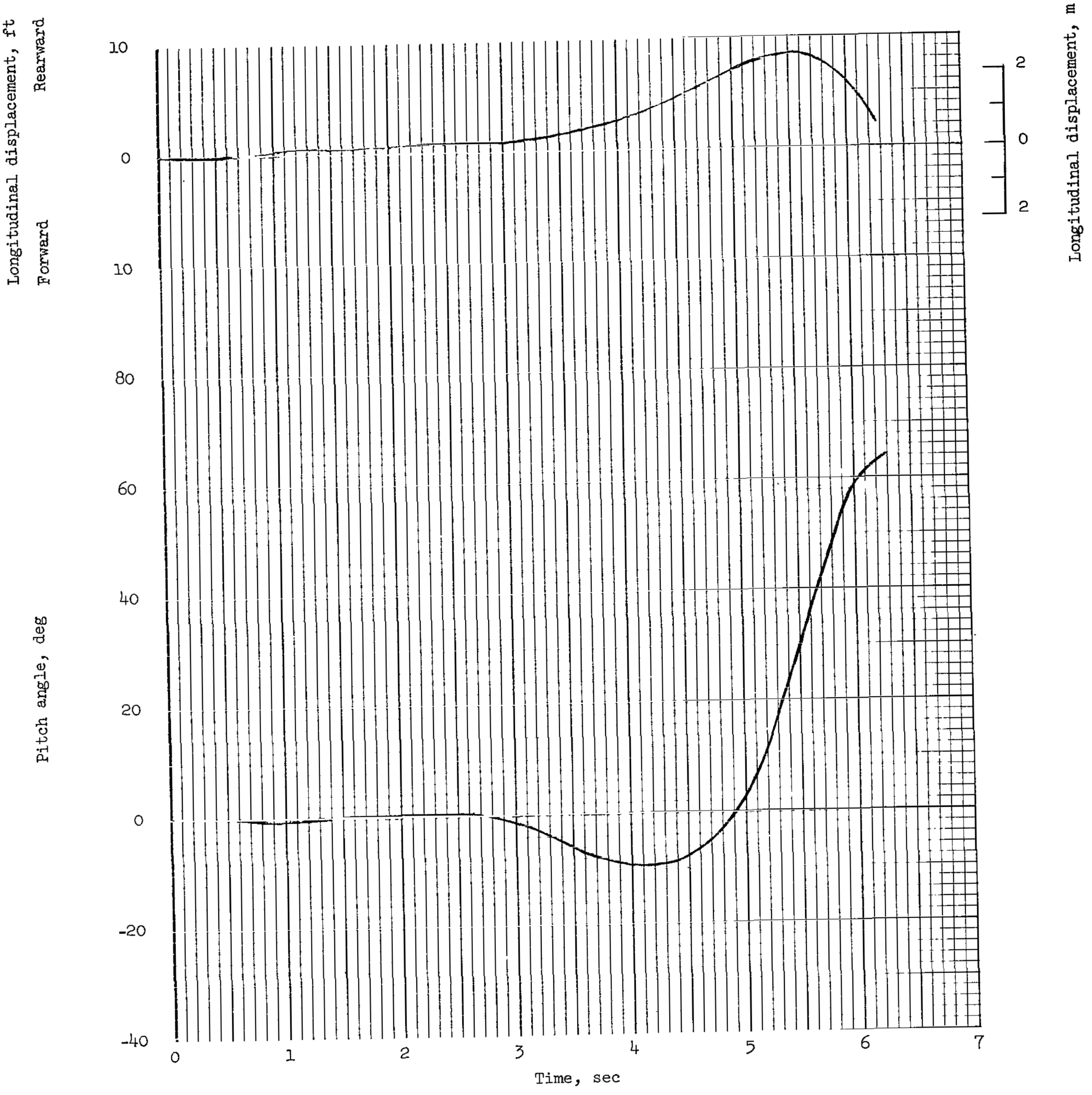


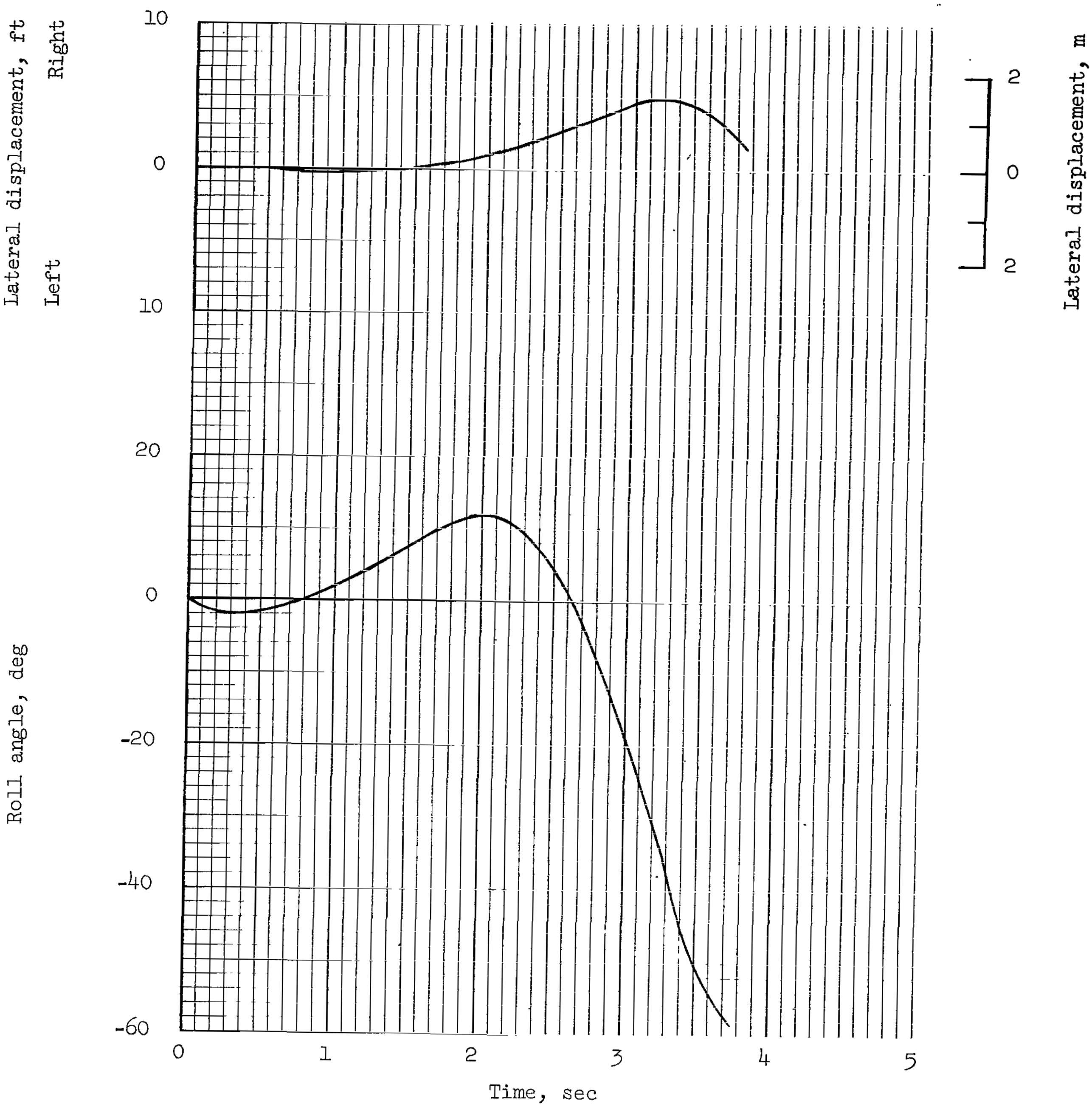
Figure 7.- Setup for flight tests in Langley full-scale tunnel.

L-64-3008



(a) Longitudinal oscillation.

Figure 8.- Typical controls-fixed motions of model in hovering flight.



(b) Lateral oscillation.

Figure 8.- Concluded.

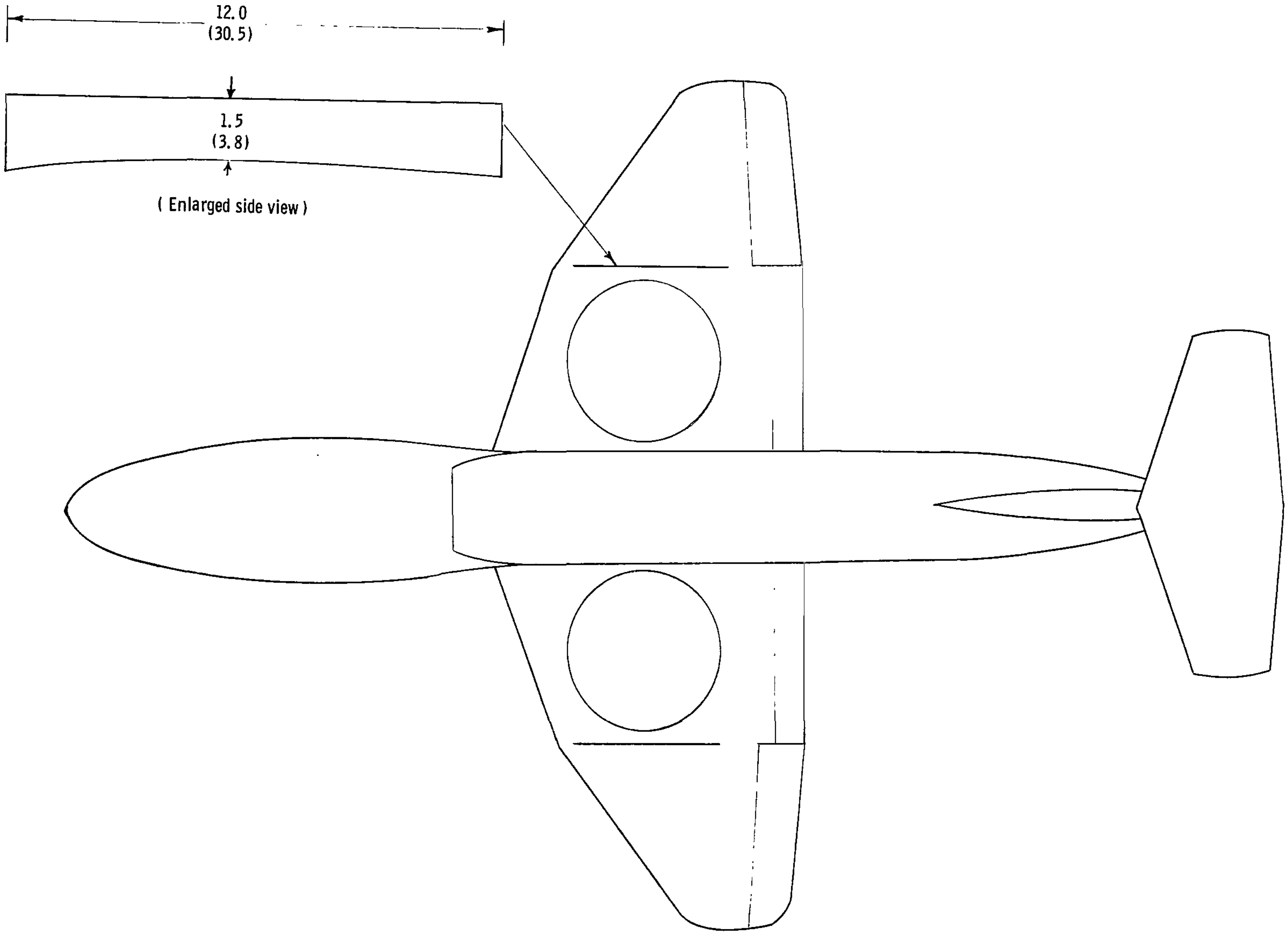


Figure 9.- Sketch showing location of wing fences added to basic model. Dimensions are given in inches and parenthetically in centimeters.

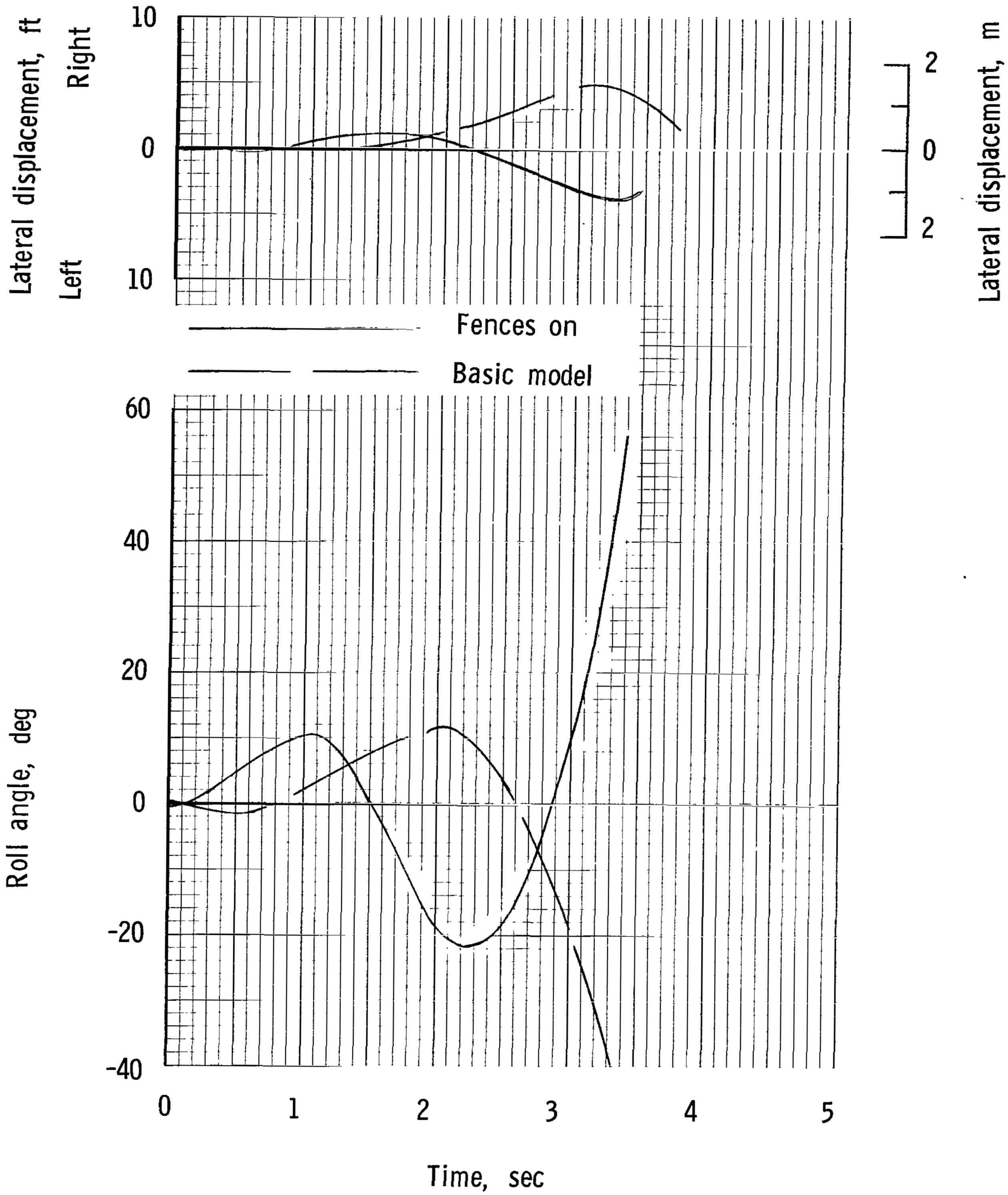
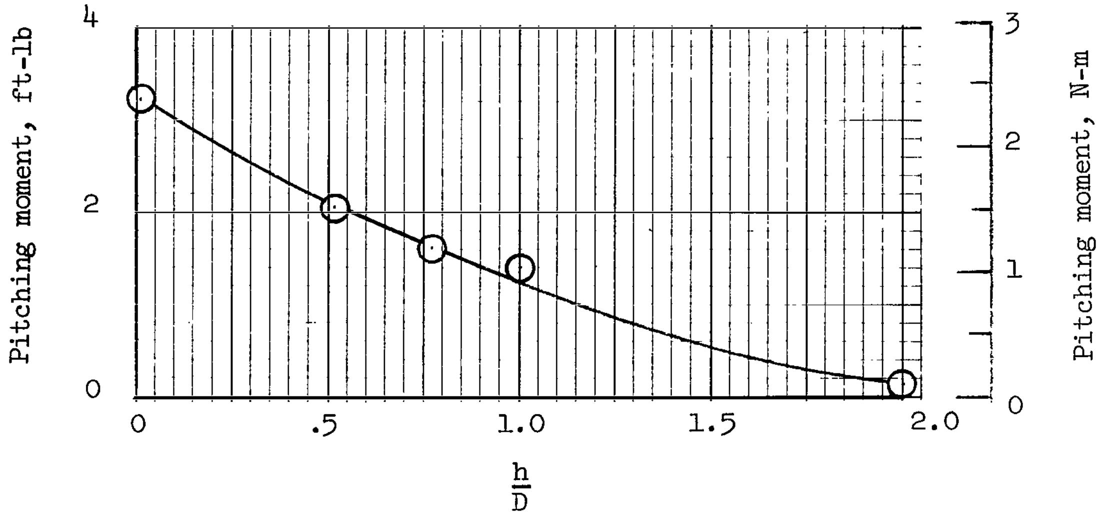
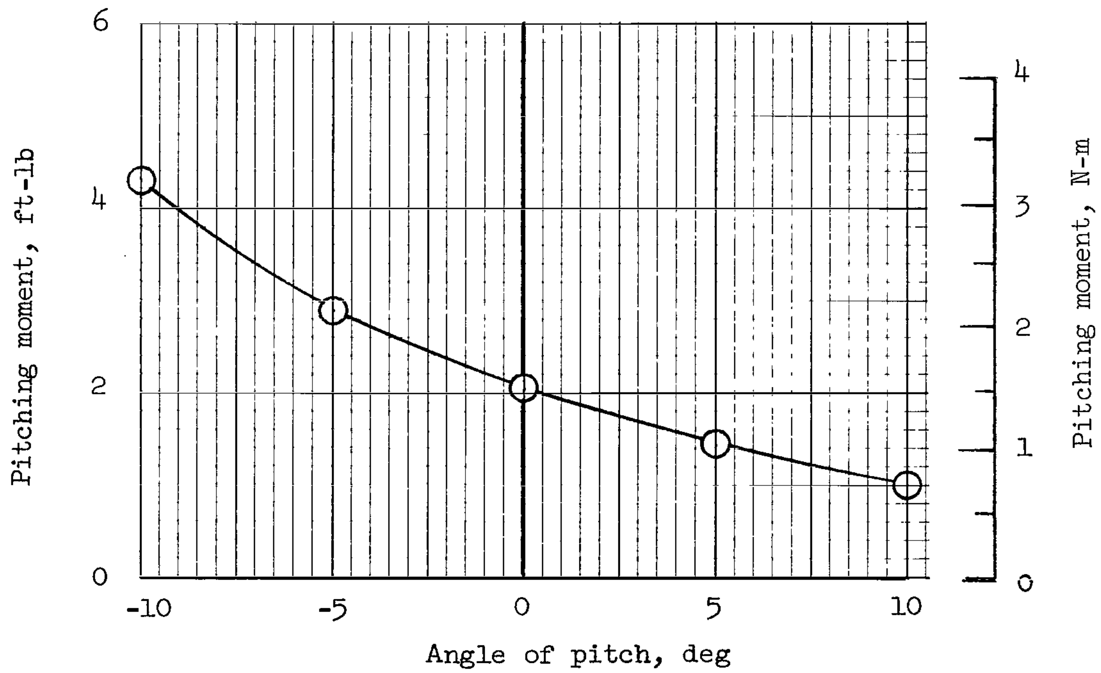


Figure 10.- Effect of fences on control-fixed rolling motion of model in hovering flight.



(a) Change in pitching-moment trim.



(b) Variation of pitching moment with angle of pitch at $h/D = 0.5$ for $\theta = 0^0$.

Figure 11.- Effect of ground proximity on model characteristics in pitch.

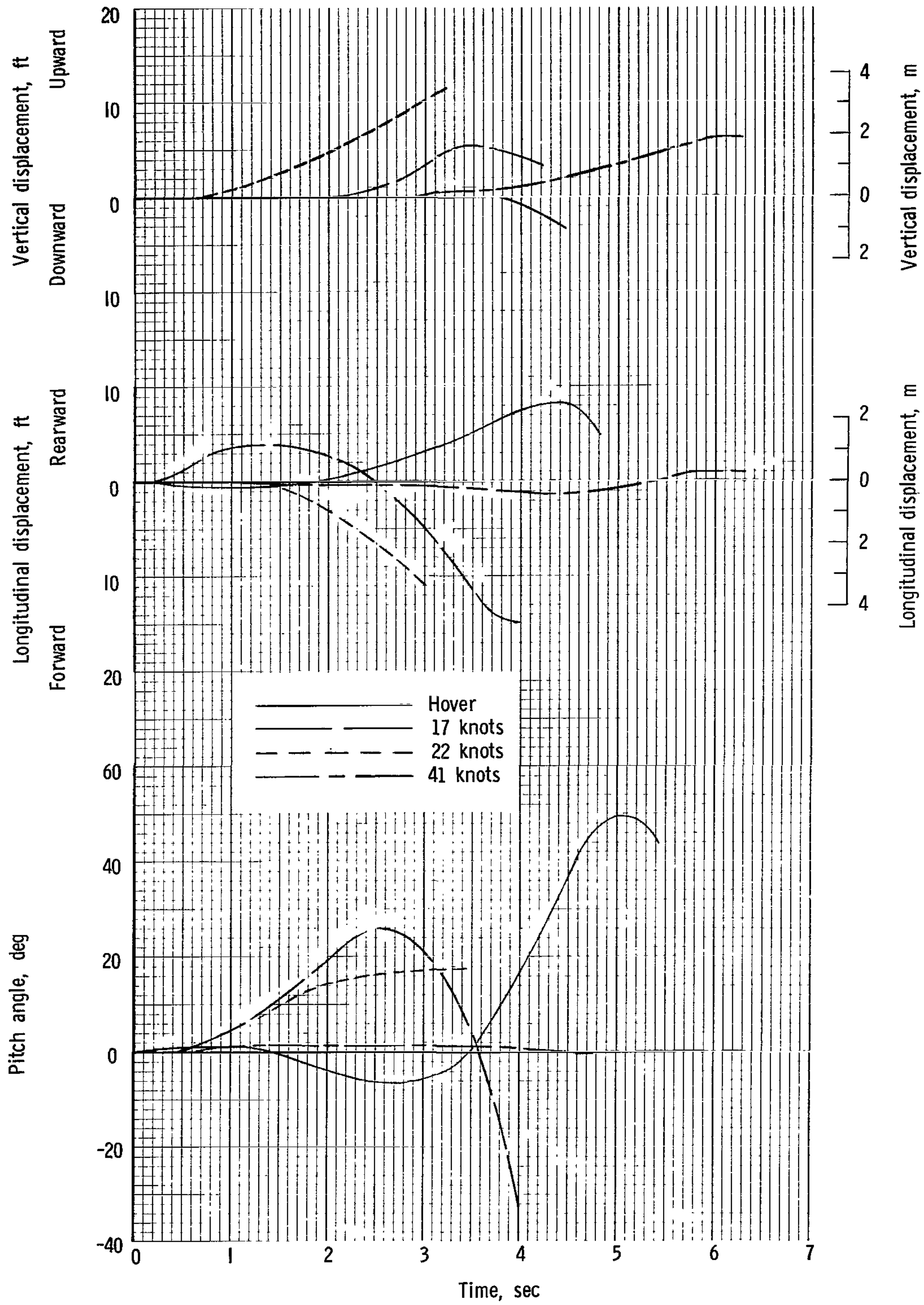


Figure 12.- Control-fixed longitudinal motions of model at several forward speeds in transition range.

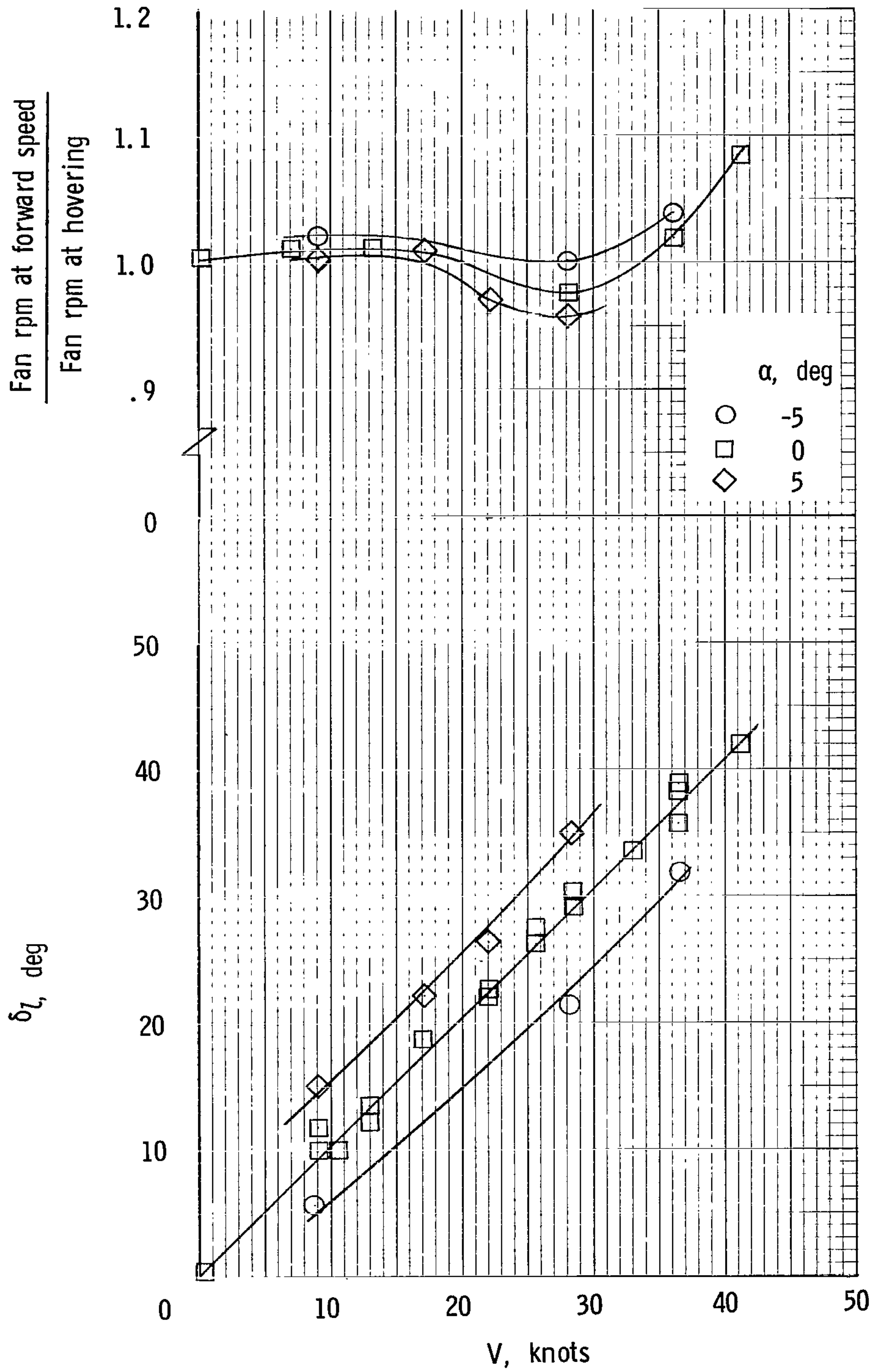


Figure 13.- Exit-louver deflection and fan speed required for trimmed level flight at several angles of attack.

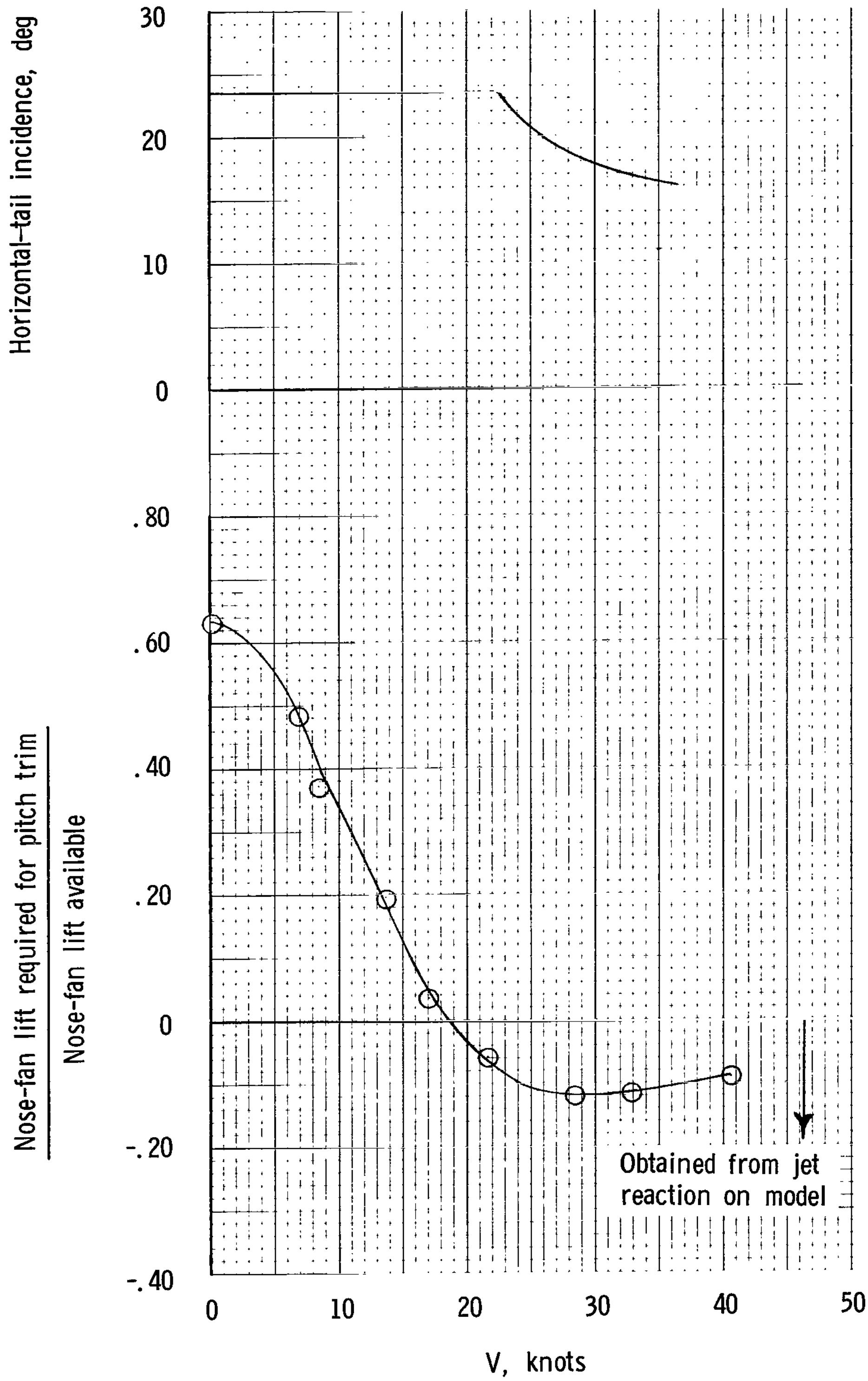


Figure 14.- Longitudinal trim required and horizontal-tail incidence used during level forward flight.

NASA-Langley, 1966 L-4943

A motion-picture film supplement L-902 is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 7 min, color, silent) shows steady hovering flight, controls-fixed motions and longitudinal controllability in hovering flight, take-offs, and steady level flight and controls-fixed longitudinal motions at several forward speeds.

Requests for the film should be addressed to:

Chief, Photographic Division
NASA Langley Research Center
Langley Station
Hampton, Va. 23365

CUT

Date ____________

Please send, on loan, copy of film supplement L-902 to TN D-3412

____
Name of organization

____
Street number

____
City and State Zip code

Attention: Mr. ____________

Title ____________

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546